"The Present Status of the New Resonances"

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Scientific Note No. 14
Contract No. 61(052)-265
May 30th, 1962

"The research reported in this document has been sponsored in part by the United States Government"

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*) On leave of absence from the Institute of Mathematical Sciences, Madras, India.

Abstract

This report is an attempt to collect the available experimental material on the resonances observed in systems of strongly interacting particles. It confines itself strictly to well-established facts and although references to the various phenomenological models proposed to understand these resonances are given, none of the conclusions reached purely from such models are included in our "Tables" for these resonances.

1. Introduction

We have classified the resonances into four groups corresponding to the baryon number and strangeness combinations B = 1, S = 0; B = 1, S = -1; B = 0, S = 0 and B = 0, |S| = 1. No resonance of the type B = 1, S = 1 has as yet been observed and consequently no fifth class appears characterized by these quantum numbers. In Sections 2-5, we give short summaries of the available information on the resonances in each of these classes. In these Sections may also be found brief references to the more speculative work in this field. In the Tables, we have tabulated the various quantum numbers of these resonances. The masses of the resonances given here have been calculated as the mean of the values given by the experiments with the smallest errors. Finally we list the references from which the preceding material has been collected. *)

2. The π-N-Resonances

The references for the π-N scattering have been tabulated in the energy range of 340 to 1500 MeV for the pion laboratory kinetic energy. These have been classified under various headings for ease of reference. References to the experiments in the energy range of the (3/2, 3/2) resonance have been omitted since the data involved here are rather well-known. (See for instance the review articles No.(163) and No.(168)).

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*) We have attempted at completeness of references, but no doubt we have not succeeded very well in this task, and we wish to apologize to all those authors towards whom we have been guilty of sins of omission.

The π-N resonant states have been intensively investigated in the π-N elastic and inelastic scattering processes as well as in the photoproduction processes $\gamma + p \rightarrow p + \pi^0$ and $\gamma + p \rightarrow n + \pi^+$. The I = 1/2 cross-section for π-N scattering shows two marked resonances, one (the N**) at 151o MeV with a half-width of 3o MeV and the other (the N***) at 168o MeV with a half-width of 5o MeV. The spin and parity of these resonances have been determined in the photoproduction experiments by studying the angular distributions and polarization of the recoil proton (in the reaction $\gamma + p \rightarrow p + \pi^0$). These reveal that N** is in the $D_{3/2}$ and N*** in the $F_{5/2}$ state. In the π^+ p scattering cross-sections, there appears a hump at an energy of about 19oo MeV with a half-width of about 1oo MeV which probably is a resonance of some kind. The spin and parity of this resonance (the N****) are not well established. There also appears what looks like another resonance in the cross-section curves at an energy of about 165o MeV.[153), 167)] All these data are summarized in Table I.

Layson[153)] has proposed a phenomenological model for these resonances which predicts in all eight π-N resonances in various isotopic spin and angular momentum states. His analysis of the data also suggests that the 165o MeV resonance is in the $D_{5/2}$ and the 19oo MeV resonance in the $F_{7/2}$ state. For details, we refer the reader to Layson's papers[153)].

3. The Y* Resonances

a) The Y*: In Table II, we have quoted a mass value of 138o MeV for this resonance. This agrees (within the experimental uncertainties) with the accurate measurements of O.I. Dahl et al.[17o)] and of J.P. Berge et al.[171)] (who give a value of 1382 ± 3 MeV and 1385 ± 5 MeV respectively). It agrees also with older experiments, but it is slightly outside

the range of uncertainty of the mass value given by R.P. Ely et al. [173] (which is 1376 $\pm$ 3 MeV). The quoted half-width is the average of all the measured values given by those experiments in which the energy resolution is smaller than the half-width. R.P. Ely et al. [173] obtain $\Gamma/2 = 24 \pm 4$ MeV for Y_1^{*+} and 33 $\pm$ 5 MeV for Y_1^{*-}.

The quoted spin assignment is the most recent one by R.P. Ely et al. [173] obtained through an Adair analysis.

The branching ratio for the decay into $\Sigma + \pi$ is the value given by P. Bastien et al. [174]; we would however draw the reader's attention to the authors' remark that "This average (2 $\pm$ 2 %) must be used with some reservation since the 5 input data are not very consistent."

The reaction $K^- + \mathcal{N} \longrightarrow Y_1^{*o}$ is to be understood as a K^- scattering on a nucleon bound in a nucleus. This process has been observed by Y. Eisenberg et al. [175] who find that the mass of Y_1^{*o} seems to be greater than the mass of $Y_1^{*\pm}$ by 10- 15 MeV. It is however not certain that all the events observed are those of Y_1^* and many of the events could be due to Y_0^*-decay's. (See Y. Eisenberg [176] and R. Cester [177].)

b) The Y_0^* : The mass of Y_0^* has been found to be 1405 MeV by M.H. Alston et al. [188] They find in addition that the total energy in the center-of-mass system of the decay products (i.e. the effective mass) is 19 $\pm$ 6 MeV higher for uncharged decay products ($\Sigma^0 + \pi^0$) than for the charged ones ($\Sigma^\pm + \pi^\mp$).

By $K^- + \mathcal{N} \longrightarrow Y_0^*$ we understand again the scattering of a K^- on a nucleon bound in a nucleus.

c) The Y_0^{**} : This resonance has been observed as a Breit-Wigner Maximum in the K^--p total cross-section (indicated in the Table as the process $K^- + p \rightarrow Y_0^{**}$) by M.Ferro-Luzzi et al. [189]. Their spin parity assignment to this resonance is able to fix the relative Σ-Λ parity as even. (R.D. Tripp et al. [190].)

d) The Y_0^{***} : This resonance has also been found as a maximum in the K^--p total cross-section ($K^- + p \rightarrow Y_0^{***}$). See also the older total cross-section measurements by V. Cook et al. [192].

4. The Pion Resonances

In the column "Spin-Parity" of Table III we have added a third column where we list the "G-parity" of these states. The G-parity operation is defined as charge-conjugation operation times a rotation around the 2nd axis in the isotopic-spin space by 180°, i.e.

$$G = C \cdot e^{i\pi T_2}$$

The assignment of these quantum numbers for the pion resonances implies certain selection rules for the decay of these states and we reproduce a list of these selection rules below. (See e.g. B.T. Feld [193], H.P. Duerr and W. Heisenberg [194].)

Selection Rules for π- decays:

	T = 0	2π	3π	4π	T = 1	2π	3π	4π		$N\bar{N}$ state
	0^{++}	yes	P,G	yes	0^{+-}	G	P	G		$^3P_0$
η?	0^{-+}	P	G	yes	0^{--}	P,G	yes	G	π	$^1S_0$
	1^{+-}	P	yes	yes	1^{++}	P	G	yes		$^1P_1$
	1^{++}	P	G	yes	1^{+-}	P	yes	yes		$^3P_1$
ω	1^{--}	G	yes, no $3\pi^0$	G	1^{-+}	yes	G	yes	ρ	$^3S_1$

In this table, selection rules for the 2π, 3π and 4π decays are listed for both T = 0 and T = 1 states with various spin-parity-G-parity combinations. "Yes" means an allowed transition. P means that the transition is forbidden by parity conservation, i.e. it is only allowed via weak interactions. Similarly, G denotes electromagnetically allowed decays which are however forbidden in the presence of strong interactions alone. The last column lists the nucleon-antinucleon states with the same quantum numbers as the resonant states (here only S and P waves are considered).

a) The η-meson:

The mass of the η particle has been measured by P.L. Bastien et al. [195] to be 548 $\pm$ 2 MeV for the charged η and 55o $\pm$ 1,5 MeV for the η-mode decaying into $3\pi^0$. Combining it with the 546 MeV found by A. Pevsner et al. [196], we quote a value of 548 MeV.

The spin-parity assignment has been made by P.L. Bastien et al. [195], from a Dalitz-plot to be 0^{-+}, but with very poor statistics. However, the narrow width and the branching ratio for neutral decays support this assignment. Further, for a 1^{--} η, the branching ratio for a ρ (see d)) decaying into $\eta + \pi$ has been estimated by G. Feinberg [197] to be 3/4 and by A.H. Rosenfeld et al. [198] to be 1/4. Such decays have been searched for by the latter authors and have not been found. It should however be mentioned that the estimates made by M. Gell-Mann et al. [199] for this branching ratio are appreciably lower ($\sim$1/1oo) than the ones quoted above. S. Hori et al. [2oo] also obtain a very low ratio, but they do not take into account the angular momentum barrier and other momentum-dependent factors. We therefore quote the assignment 0^{-+} in the Table in paranthesis.

For the isospin assignment to this resonance, see D. D. Carmony et al. [2o1].

b) The Υ-meson:

An indication for this resonance already appears in the π-π cross-section curves obtained by A.R. Erwin et al. [2o2] as a second hump besides the one for the ρ-particle. The quoted mass is the mean of all quoted experiments.

c) The ω-meson:

The mass value is again the mean of all experiments (787, 764 and 78o MeV). The spin-parity assignment is due to M.L. Stevenson et al. [2o5].

d) The ρ-meson:

The nature of this resonance seems to be rather complicated. Although it has been observed in many different processes and even in the extrapolated π-π cross-section curves, its mass and half-width are still slightly uncertain since the values obtained are different in different experiments. It might even be that it is actually composed of two unstable particles, but no definite results have as yet been published.

e) The ABC-particle:

For completeness, we add some comments on another resonance which has been found as a spectrum anomaly in the reaction $p + d \rightarrow He^3 + \pi^+ + \pi^0$ by A. Abashian, N.E. Booth and K.M. Crowe [216),217]. They found a hump suggesting a π-π resonance at 31o MeV. Since then, it has been looked for unsuccessfully in photoproduction reactions by K. Berkelman et al. [218]. Further, the results of Abashian et al. can be well explained as purely due to final state interactions (see T.N. Truong [219] or A. Tubis and J.L. Uretsky [22o]). For these reasons, we have not included this "resonance" in the Table.

5. The K-π Resonance

Alston et al.[221] have found a K-π resonance in the study of the reactions

$$K^- + p \longrightarrow K^- + \pi^0 + p \qquad a)$$

$$\bar{K}^0 + \pi^- + p \qquad b)$$

The resonance ($\bar{K}$*) appears with a mass value of 885 MeV and a remarkably narrow half-width of 8 MeV [170]. The isospin of the resonance has been measured by studying the ratio of the rates of the reactions (a) and (b) for those energy values of the ($\bar{K}$-π) system which lie within the K-π resonance region. The expected ratio for $\frac{(\bar{K}^0\pi^-)}{(K^-\pi^0)}$ is 0.5 for an I = 3/2 $\bar{K}$* and 2 for an I = 1/2 $\bar{K}$*. The experimental ratio is 1.4 ± o.4 which therefore favours an I = 1/2 resonance. An Adair type analysis for the decay $\bar{K}^{*-} \rightarrow \bar{K}^0 + \pi^-$ has been carried out which indicates an essentially isotropic angular distribution for the decay products giving J = 0 or 1 for the $\bar{K}$* [221]. A number of arguments have appeared stemming essentially from the narrow width of the K* suggesting that the actual spin assignment is J = 1 [224)-226)].

The antiparticles of $\bar{K}$* have also been observed by Erwin et al.[222] and by Alitti et al.[223] in the study of the reactions

$$\pi^- + p \longrightarrow \Sigma^- + K^0 + \pi^+$$

$$\Sigma^- + K^+ + \pi^0$$

The mass distribution curve of the π-K system given by Erwin et al.[222] seems to have another hump at an energy of about 78o MeV which may indicate yet another K-π resonance at this energy.

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Acknowledgements

We wish to thank Prof. W. Thirring for his kind interest in this work and the members of our Bubble Chamber Group for help. One of us (A.P.B.) wishes to thank Prof. Thirring for the warm hospitality offered him at the Institute for Theoretical Physics and for financial assistance.

TABLE I

I. $B = 1$, $S = 0$. [πN treshold at 1098 MeV].

Nr.	Symbol		Mass (MeV)	$\Gamma/2$ (MeV)	Spin-Parity
	$T = \frac{1}{2}$	$T = \frac{3}{2}$			
1		N^{*}	1238	45	$\frac{3}{2}$ +
2	N^{**}		1510	30	$\frac{3}{2}$ −
3	N^{***}		1680	50	$\frac{5}{2}$ +
4		N^{****}	1900	≈ 100	¿

TABLE II

II. $B = 1,\ S = -1$ [$\pi\Lambda$ treshold at 1255 MeV, $\bar{K}N$ treshold at 1432 MeV].

Nr.	Symbol T = 0	Symbol T = 1	Mass	$\Gamma/2$	Spin-Par.	Decay Products	Ratio	Ref.	Observed Production Reaction	Ref.
5		Y_1^*	1380	~ 22	$\geq 3/2$	$\Lambda + \pi^-$			$K^- + p \to Y_1^* + \pi$	171, 173, 174, 178 to 181
						$\Lambda + \pi^+$			$K^- + n \to Y_1^{*\frac{0}{-}} + \pi^{\frac{-}{0}}$	181, 182
						$\Lambda + \pi^0$				
						$\Sigma^+ + \pi$	$(2 \pm 2)\%$	174	$K^- + d \to Y_1^{*-} + p$	170
									$K^- + He^4 \to Y_1^{*-} + He^3$	183, 184
									$K^- + \underline{\mathcal{N}} \to Y_1^{*0}$	175
									$K_2^0 + p \to Y_1^{*\frac{+}{0}} + \pi^{\frac{0}{+}}$	185, 186
									$\pi^- + p \to Y_1^{*\frac{0}{-}} + K^{\frac{0}{+}}$	187
6	Y_0^*		1405	20	?	$\Sigma^\pm + \pi^\mp$			$K^- + p \to Y_0^* + \pi^0$	174
						$\Sigma^0 + \pi^0$	$(37 \pm 7)\%$	188	$K^- + p \to Y_0^* + \pi^+ + \pi^-$	188
									$K^- + \underline{\mathcal{N}} \to Y_0^*$	175, 176
7	Y_0^{**}		1520	8	$3/2\,-$	$\bar{K} + N$	1/3	189	$K^- + p \to Y_0^{**}$	189
						$\Sigma + \pi$	5/9	189	$K^- + p \to Y_0^{**} + \pi^0$	174
						$\Lambda + 2\pi$	1/9	189		
8	Y_0^{***}		1812	60					$K^- + p \to Y_0^{***}$	191

TABLE III

III. B = 0, S = 0.

Nr.	Symbol T = 0	Symbol T = 1	Mass MeV	Γ/2 MeV	Sp P G.	Decay Products	Ratio	Ref	Observed Production Reaction	Ref.
9	η		548	< 3,5	(0^{-+})	$\pi^+ + \pi^- + \pi^0$	(24 ± 6)%	195	$\pi^+ + d \to p + p + \eta$	196
						$3\pi^0$	(76 ± 6)%		$K^- + p \to \Lambda + \eta$	195
10		ζ	560	< 8	(1?)	$\pi^+ + \pi^0$			$\pi^+ + p \to \zeta^+ + p$	203
						$\pi^- + \pi^0$			$\pi^- + p \to \zeta^- + p,\ \zeta^0 + n$	202
						$\pi^- + \pi^+$			$p + p \to \zeta^+ + d$	204
11	ω		777	< 12	1^{--}	$\pi^+ + \pi^- + \pi^0$			$\pi^+ + d \to p + p + \omega$	196
									$p + \bar{p} \to \pi^+ + \pi^- + \omega$	205, 206
									$p + \bar{p} \to 2\pi^+ + 2\pi^- + \omega$	207
12		ρ	~ 750	~ 65	1^{-+}	$\pi^+ + \pi^0$			$\pi^- + p \to p + \rho^-,\ n + \rho^0$	202, 208 - 212
						$\pi^- + \pi^0$			$\pi^+ + p \to p + \rho^+$	213, 214
						$\pi^- + \pi^+$			$\gamma + p \to p + \rho^0$	215
						$\pi^0 + \pi^0$	< 8%	202	$p + \bar{p} \to 2\pi + \rho$	206
						$\eta + \pi^+$	< (0,6 ± 0,2)%	198		

TABLE IV

IV. $B = 0, |S| = 1.$

Nr.	Symbol $T = 1/2$	Symbol $T = 3/2$	Mass MeV	$\Gamma/2$ MeV	Spin Parity	Decay Products	Ratio	Ref.	Observed Production Reaction	Ref.
13	K^*		885 ± 3	8	$S =$ 0 or 1	$\bar{K}^{*-} \to K^- + \pi^0$ $\to \bar{K}^0 + \pi^-$	$0{,}75 \pm 0{,}35$ (i.e. $I = 1/2$)	221 see also 222, 223	$K^- + p \to \bar{K}^0 + \pi^- + p$ $\Sigma^- + K^{*+} \to \Sigma^- + K^0 + \pi^+$ $\to \Sigma^- + K^+ + \pi^0$	221 165 222, 223

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